Densities of Juvenile Atlantic Salmon as Indicators of Standing Populations on the Miramichi River System

T.L. Marshall

Freshwater and Anadromous Division
Fisheries Research Branch
Department of Fisheries and Oceans
Halifax, Nova Scotia, B3J 2S7

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Department of Fisheries and Oceans
Halifax, Nova Scotia
B3J 2S7

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CONTENTS

LIST OF TABLES. v

ABSTRACT/RÉSUMÉ vii

INTRODUCTION. 1

MATERIALS AND METHODS 1

RESULTS 2

DISCUSSION. 3

ACKNOWLEDGEMENTS. 3

REFERENCES. 11

LIST OF TABLES

TABLE 1. Site numbers of Miramichi electroseining stations (Peppar and Schofield 1978) categorized by stream order and included in the analysis. 5

TABLE 2. Numbers of data sets - a) eggs to fry, 1969-80; b) fry to small parr, 1978-80; c) small parr to large parr, 1978-80 - by year and stream order, for the Miramichi River, New Brunswick 6

TABLE 3. Correlation coefficients (r) and their significance (p) from regressions of individual values of small parr on fry (n_{total} = 527), large parr on small parr (n_{total} = 529) and mean annual fry densities on estimated annual egg deposition (n_{total} = 11) for five stream orders of the Miramichi River, N.B., 1969-80. 7

TABLE 4. ANCOVA tables for fry (11 pairs of data) and parr (10 pairs of data) densities in five stream orders of the Miramichi River, N.B., 1969-80. 7

TABLE 5. A. Mean annual fry and adjusted mean annual small- and large-parr densities, by stream order, for the Miramichi River, 1970-80. B. Significantly different stream orders based on densities within the fry, small- and large-parr categories for the Miramichi River, 1970-80 8

TABLE 6. A. Unadjusted mean annual fry, small-parr and large-parr densities, by stream order, for the Miramichi River, 1970-80. B. Survival rates for fry to small parr and small parr to large parr for each stream order of the Miramichi River, 1970-80 9

ABSTRACT

Marshall, T.L. 1983. Densities of juvenile Atlantic salmon as indicators of standing populations on the Miramichi River system. Can. MS Rep. Fish. Aquat. Sci. No. 1727. vii + 11 p.

In the Miramichi River system, New Brunswick, densities of Atlantic salmon (Salmo salar) fry, small parr and large parr - established for as many as 72 electroseining sites per year between 1970 and 1980 were analysed according to stream-order designation for their potential to reflect total river standing populations. Analyses of covariance applied, because a demonstrated correlation between numbers of juveniles of Age n + 1 and juveniles of Age n in the previous year indicated that there were significant differences in the numbers of fry and parr in different stream orders and years. Survival rates of small parr from fry declined between upper and lower reaches of the river. Survival rates of large parr from small parr were not significantly different between reaches. Together the two sets of survival rates contributed to the conclusion that juvenile density estimates for lower river reaches, which comprise about 56% of the total Miramichi production area, could inadequately reflect total standing populations.

Key words: Miramichi River, Atlantic salmon, fry, small parr, large parr, electroseining, juvenile densities, index of abundance, stream-order designation, representativeness.

RÉSUMÉ

Marshall, T.L. 1983. Densities of juvenile Atlantic salmon as indicators of standing populations on the Miramichi River system. Can. MS Rep. Fish. Aquat. Sci. No. 1727. vii + 11 p.

La densité des alevins et des tacons de petite et de grande taille dans le réseau de la rivière Miramichi, au Nouveau-Brunswick -- mesurée à un nombre de sites de sennage électrique aussi élevé que 72 par année entre 1970 et 1980 -- a été analysée par ordre de cours d'eau, en vue de déterminer si cette densité pouvait être un indice des populations statique de la rivière. On a pu faire appel à des analyses de covariance puisqu'une corrélation entre le nombre de juvéniles d'âge n + 1 et ceux d'âge n l'année précédente a indiqué des différences significatives entre les nombres d'alevins et de tacons dans des cours d'eau de différents ordres et en différentes années. Les taux de survie de petits à grands tacons étaient a la baisse depuis le cours supérieur et inferieur de la rivière. Les taux de survie de petits à grands tacons n'étaient pas significativement différents entre le cours supérieur et inférieur de la rivière. Ensemble, les deux séries de taux de survie ont permis de conclure que les estimations de la densité des juvéniles dans la partie inférieure de la riviére, comprenant environ 56 % de la production totale de la Miramichi, ne pouvaient refléter adéquatement les populations statiques totales.

INTRODUCTION

Use of juvenile salmon population densities derived from standard electroseining procedures has become of increasing interest in the assessment of the status of Atlantic salmon. Of greatest concern has been the question of the representativeness of sample densities relative to the total production area, particularly in larger river system where certain habitat types might be ineffectively sampled.

Selection of electroseining sites is seldom, if ever, made strictly randomly. Reasons include absence of labor-intensive quantitative ground surveys of habitat types, limited vehicle access to rivers and inability to sample effectively the turbulent or more than waist-deep waters. Number of sites has been invariably restricted by both manpower and budgetary limitations.

In most cases, analysis of derived juvenile densities has reduced all system site densities of fry, small parr and large parr to a mean value or "index of abundance" for that system. Annual repetition of sampling the same sites was presumed to provide a measure of stability or trend in juvenile levels for that river system. Because of the unknown representativeness of the sites relative to the actual salmon-producing habitat, such indexes are inappropriate for comparison between systems or for use as an estimate of mean densities for standing populations in a river system. Hence, past effort to correlate various juvenile stages with smolt production (Paloheimo and Elson 1974) and recent attempts to correlate mean fry density with sport catch the previous year could be misleading, if the sampling were not, in fact, representative of the habitats.

Attempts to gain new meaning from available juvenile data are dependent on assumptions about the potential habitat representativeness of a particular site or a number of sites. Recent approaches include that of Chadwick (pers comm.)[1], who suggested that juvenile production (biomass) in the Little Codroy River, Newfoundland, varied according to reach or stream order. A smolt production model for the Margaree River, Nova Scotia, is based on assumed representativeness of specific sites for surveyed and quantified adjacent reaches of the river. Stream-order designation, which attempts to group systematically all streams that have nearly the same width, depth, water flow and in some cases, bottom substrate, and fish species composition (Platts 1979), appeared to be a potential method of testing hypotheses about site representativeness essential to derivation of weighted, standing population estimates of juvenile salmon for use in a smolt-production model.

[1]E.M.P. Chadwick, Dept. Fisheries and Oceans, P.O. Box 5030, Moncton, N.B.

MATERIALS AND METHODS

The Miramichi River system of northeastern New Brunswick has been appropriately described by Elson (1967) and Kerswill (1971). Electroseining data (fish density/83.6 m^2) used in this analysis were collected in the Northwest and Southwest Miramichi River drainages and drawn from Peppar and Schofield (1978) for the period 1970-77, and from unpublished summaries by the same authors for the period 1978-80. Sites included those fished in at least four of the 11 years and which were accessible to adults and juveniles from 1969 to 1980. Recent data were converted from density/100 m^2 to density/83.6 m^2. Absolute 0 values (1978-80), <1 values being $> 0 < 1$ (1978-80) and <1 values being $\geq 0 < 1$ (1970-77) were all entered as 0.5.

Published estimates of densities derived by the regression method of DeLury (1947) from the number of juveniles removed in five electroseining sweeps were assumed to be the result of a significant fit of a regression line to the data. However in a superficial examination of the raw data for about 25 seemingly excessive values, approximately 50% were non-significant and subsequently either deleted from the data set or replaced by values based on sweeps of most uniform effort. It was also assumed that division into fry, small parr and large parr, on the basis of mode distributions, equated to age 0+, 1+ and 2+, respectively.

Estimates of Miramichi River egg deposition were derived from unpublished summaries of annual Millbank spawner counts, ratio of one- and two-sea-winter fish, sex composition, mean weights and the assumption of a production of 1760 eggs/kg of female body weight.

Seven stream orders were designated for the Miramichi in the manner of Strahler (1952 and 1957), cited in Platts (1979), from 1:50,000 National Topographic Series maps produced and printed by the Surveys and Mapping Branch, Dept. Mines and Technical Surveys, 1955 through 1958. Ordering commenced with 1st-order streams being the first recognizable headwater. The joining of two 1st-order streams produced a 2nd-order stream, etc. The numbered electroseining sites used and their stream-order categories are summarized in Table 1.

Preliminary analysis suggested that the density of a particular juvenile age-class in one year tended to be correlated with its density in the previous year, i.e., fry in one year were correlated with eggs the previous year, small parr were correlated with fry in the previous year and large parr were correlated with small parr the previous year. To increase precision and reduce bias in deriving and comparing mean densities of any juvenile

stage in a stream order, paired data (fry on egg, small parr on fry and large parr on small parr) were subjected to a 2-way unbalanced analysis of covariance (ANCOVA) by using Program 2V of the Biomedical Computer Programs, P-Series, (BMDP-79 1979) with five treatments (stream orders), 10 or 11 blocks (years) and the X variable as covariate. BMDP-2V tests of significance were considered approximate, but adequate where the interaction approached non-significance.

Adjusted means $[\bar{Y}_1 - b\,(\bar{X}_1 - \bar{\bar{X}})]$, where

$\bar{X}_1$ and $\bar{Y}_1$ = unadjusted arithemetic means within each stream order, b = beta estimate for 2-way ANCOVA, and $\bar{\bar{X}}$ = grand mean of the covariate,

were derived from small and large parr of each stream order.

Comparison of adjusted-treatment means between stream orders was approximated by use of the "t" statistic (Snedecor and Cochran 1980, Section 18.2), where

$$t = \frac{u_1 - u_2}{\sqrt{s^2_{y.x}\left(\frac{1}{n_1} + \frac{1}{n_2} + \frac{(\bar{X}_1 - \bar{\bar{X}})^2}{Exx}\right)}} \quad \text{and}$$

u = adjusted treatment mean
$s^2_{y.x}$ = error mean square of Y
n = number of data pairs/treatment
Exx = error sum of squares of X

Pairing of fry and egg data deviated from the above in that X values, i.e., egg data were the same for each treatment within a year. Treatment means for fry were unadjusted and tests of significance reduced to

$$t = \frac{\bar{Y}_1 - \bar{Y}_2}{\sqrt{s^2_y\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}} \quad \text{where}$$

s^2_y = error mean square from a 2-way ANOVA.

Regression analysis for small parr on fry and large parr on small parr was done with BMDP's polynomial regression. Regression of fry on eggs, i.e., where there was more than one value of Y per value of X, followed Section 14.6 of Sokal and Rohlf (1969). Survival rate is simply the proportion of an age-class of juveniles that is on location one year after its initial enumeration.

RESULTS

The number of paired data sets for each of the five treatments ranged from 46 to 179 for fry and from 41 to 150 for both age-classes of parr (Table 2). For the ten years of parr densities combined, approximately 8%, 24%, 28%, 21% and 19% of utilizable data were from 2nd-, 3rd-, 4th-, 5th- and 6th-order stream classifications, respectively. In 1980, 3%, 13%, 45%, 21%, and 18% of 38 sites were in 2nd-through 6th-order stream classifications.

Significant correlation coefficients ($p < 0.05$) from regressions of small parr in Year n on fry in Year n-1 and of large parr in Year n on small parr in Year n-1 for 9 out of 10 cases (Table 3) prompted the analysis of covariance.

Similar analyses of the dependence of fry on eggs could not be done without annual estimates of egg deposition by stream order. Linear regression of mean annual fry densities and variances on 11 estimtes of egg deposition was not significant ($F = 2.95$; $p > 0.10 < 0.25$). Simplified regressions of 11 yearly means and grand means of each stream order on the egg data suggested that 3rd- and 5th-order streams had the best potential for demonstrating a dependence of fry densities on overall egg deposition (Table 3).

Ten 2nd-order polynomials of the form $y = a + b\,x + cx^2$ were fitted to the small parr on fry and large parr on small parr data. Line plots were curved and, much like a stock-recruitment relationship, tended to an asymptote or parabola. Correlation coefficients were improved in only the small parr on fry relationship for the 2nd-order streams($R = 0.58$; $p < 0.01$). The general lack of overall improvement by 2nd-order polynomials, linear tendencies and normal distribution of the residuals justified subsequent ANCOVA. The plots, however, permitted recognition that densities, especially in headwaters, might be the result of intraspecific competition.

ANCOVA outputs are summarized for each of fry on eggs, small parr on fry, and large parr on small parr (Table 4). Significant differences occurred between numbers of fry, small parr and large parr in different stream orders and in different years.

Mean densities for fry and adjusted mean densities for small and large parr for the 10 years (parr) and 11 years (fry) in five stream orders are summarized (Table 5). Highest mean densities of fry (23.99 and 26.70/83.6 m^2), small parr (13.99 and 10.98/83.6 m^2) and large parr (5.48 and 3.12/83.6 m^2) occurred on sites within 2nd- and 4th-order streams. Low mean densities of 13.81 fry, 3.26 small parr and 1.84 large parr/83.6 m^2 occurred in 5th-, 6th- and 5th-order streams, respectively. Comparison of mean values indicated significant differences ($p < 0.05$) between densities of all juvenile stages in 2nd- and 4th-order streams and those of most higher orders (Table 5).

Average annual survival rates, herein reflecting mortality and immigration/emigration based on unadjusted mean densities for fry to small parr, declined noticeably from 0.59 in the 2nd-order streams to 0.16 in the 6th-order streams (Table 6). A Chi-square test for differences in the distribution of numbers of fry that remained as small parr and those that were missing in various stream orders was significant ($p = 0.001$). Further testing implied that the survival

rate of 0.59 for the 2nd-order streams was greater than those of the remaining stream orders ($p = 0.001$) and that the values of 0.27 and 0.16 for 5th- and 6th-order streams, respectively, were less than those for 2nd- and 4th-order streams. Survival rates for small parr to large parr ranged from 0.44 to 0.32 and were not statistically different ($X^2 = 4.95$; $p = 0.29$).

DISCUSSION

Combined total area utilizable by and accessible to Atlantic salmon above tidehead on both the Northwest and Southwest Miramichi rivers has been estimated at $54.6 \times 10^6 m^2$ (Amiro 1981). Approximately 44%, 23%, 27% and 6% of the total area can be classified as 1st- to 4th-order streams, 5th-order streams, 6th-order streams and 7th-order streams, respectively. Thus, juvenile abundance for 50%, and most likely 56%, of the total production area is presumably represented by electroseining conducted in 5th- and 6th-order streams.

With the exception of 3rd-order streams, fry abundance was not well correlated with estimated egg deposition. Lack of correlation may be due to depensatory mortality (Ricker 1975), non-random egg deposition and selected sampling of fry in proximity to spawning areas consistently used by spawners regardless of their number. In fact, there would appear to be a tendency in the Miramichi sampling to include fry-type habitat within all stream orders, since mean densities and differences between fry levels in the different orders vary the least of any juvenile measurement. Egg to early fry (≤ 4 cm) relationships might be expected to be straight-line as small fry resultant of high or low egg deposition would have insignificant territorial requirements during the June and early July portion of the electroseining season. Later sampling would, however, be expected to reflect effect of density dependence and changes in habitat preference in redistributing fry from the immediate proximity of spawning areas to more variable-sized rearing substrate.

Inferences about the representativeness of electrofishing sites of their assigned stream order can be drawn from both mean densities and derived survival rates (Table 6). Survival rates from fry to small parr, which Elson (1957) reported as 0.54 for the Pollett River and Meister (1962) found to range from 0.41 to 0.50 in Cove Brook, Maine, declined with increasing stream order. This decline contradicts an earlier suggestion that there might be higher survival rates in lower stream reaches, reflecting the residency of migrant parr displaced by density factors from upstream reaches. Barring the possibility of significantly greater predation on small parr in lower stream reaches, it is suggested that apparent low survival rates for fry to small parr in lower stream reaches (higher stream order) should be at least equal to if not greater than those of higher stream reaches. Either lower fry densities, less egg deposition or higher small parr densities would contribute to higher survival rates in lower stream reaches. Since electroseining sites in the higher 5th- and 6th-order streams are heavily comprised of 3-sided, gravel- and cobble-bottomed "shore sites" in wadeable water, it is possible that these sites are more typical of fry habitat and that sampling favors fry at the expense of small parr. Hence, the apparent low egg-to-fry survival rates in 5th- and 6th-order streams.

Hypothetical equality of survival rates between fry and small parr in all stream orders is supported by the relatively uniform survival rates between small parr and large parr (Table 6). Here, 5th- and 6th-order streams which supported only a few small parr contained residual large parr in approximately equal proportion to parr density ratios demonstrated for lower stream orders, where representative sampling of habitat variation is less suspect.

If 5th-, 6th- and 7th-order streams comprising 56% of the Miramichi production area inadequately reflect standing juvenile populations, assumptions about the utility of electrofishing as an indicator of total production must be evaluated. This should entail the quantification of general habitat "types" and the establishment of representative juvenile sampling therein. Then it may be possible to deterine and examine factors influencing in-stream survival and to predict smolt production.

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R.K. Misra suggested statistical treatment of the data and interpretation of the output. J.T. O'Neil processed the data on computer. J.L. Peppar and E.J. Schofield provided unpublished electroseining results for recent years and background data to published materials. R.E. Cutting, R.K. Misra and B.M. Jessop reviewed earlier drafts of the manuscript.

TABLE 1. Site numbers of Miramichi electroseining stations (Peppar and Schofield 1978) categorized by stream order and included in the analysis.

Stream	Stream orders				
	2	3	4	5	6
	Site numbers of electroseining stations				
Little River		2, 12			
Portage River		8	1		
Little Sevogle River		1, 2, 3			
Little Southwest Miramichi River	4		6	1,3	
Sutherland Brook	1				
Northwest Millstream		1			
Big Sevogle River			2, 3	1	
Northwest Miramichi River		18, 19	13, 15, 17	4, 5, 7, 9A, 9B	2
Dungarvon River			1, 2, 3		
Barnaby River		1, 2			
Renous River		5	8	2, 3, 6, 7	
Main Southwest Miramichi River			8	9, 12	7, 4, 10, 14, 11, 6 5, 13, 1, 2, 3
Morse Brook		1			
Cains River				3, 6, 8	4
Big Hole Brook		2, 3	1		
Betts Mill Brook			1, 2		
Burntland Brook			1, 2		
Taxis River		2, 3	1		
MacBean Brook	1, 2				
Rocky Brook			1, 2, 4		
Teague Brook	2	1			

TABLE 2. Numbers of data sets - a) eggs to fry, 1969-80; b) fry to small parr, 1978-80; and c) small parr to large parr, 1970-80 - by year and stream order, for the Miramichi River, New Brunswick.

	Year	Stream order 2	3	4	5	6	Totals
		Number of data sets					
a)	1969-70	4	9	6	4	11	
	1970-71	5	11	10	9	12	
	1971-72	5	13	12	10	10	
	1972-73	5	14	13	11	12	
	1973-74	5	18	21	16	12	
	1974-75	5	17	21	16	13	
	1975-76	5	17	17	15	10	
	1976-77	5	17	21	16	11	
	1977-78	5	17	21	16	12	
	1978-79	1	6	18	10	7	
	1979-80	1	6	19	8	7	
	All	46	145	179	131	117	618
b)	1970-71	4	9	6	4	11	
	1971-72	5	11	10	8	10	
	1972-73	5	13	12	10	10	
	1973-74	5	14	13	11	12	
	1974-75	5	17	21	16	11	
	1975-76	5	17	15	14	10	
	1976-77	5	17	17	15	9	
	1977-78	5	17	21	16	11	
	1978-79	1	6	18	10	7	
	1979-80	1	5	17	8	7	
	All	41	126	150	112	98	527
c)	1970-71	4	9	6	4	11	
	1971-72	5	11	10	8	11	
	1972-73	5	13	12	10	10	
	1973-74	5	14	13	10	12	
	1974-75	5	17	21	17	12	
	1975-76	5	17	17	15	9	
	1976-77	5	17	15	15	9	
	1977-78	5	17	21	16	11	
	1978-79	1	6	19	10	7	
	1979-80	1	5	16	8	7	
	All	41	126	150	113	99	529

TABLE 3. Correlation coefficients (r) and their significance (p) from regressions of individual values of small parr on fry (n_{total} = 527), large parr on small parr(n_{total} = 529) and mean annual fry densities on estimated annual egg deposition (n_{total} = 11) for five stream orders of the Miramichi River, N.B., 1969-80.

Variables	Stream order					
	2	3	4	5	6	All
	Correlation coefficients (r)/significance (p)					
Fry on eggs	0.29	0.75	0.53	0.59	0.52	0.64
	0.05	0.01	0.05	0.05	0.05	0.05
Small parr on fry	0.36	0.54	0.41	0.26	0.16	0.40
	0.05	0.01	0.01	0.01	0.05	0.01
Large parr on small parr	0.66	0.62	0.49	0.12	0.33	0.56
	0.01	0.01	0.01	0.05	0.01	0.01

TABLE 4. ANCOVA tables for fry (11 pairs of data) and parr (10 pairs of data) densities in five stream orders of the Miramichi River, N.B., 1969-80.

Treatment	Source of variation	Degrees of freedom	Mean square	F	Beta estimate
Fry on eggs					
	Stream order	4	3,820.97	7.88	
	Years	10	3,766.33	7.77	
	Interaction	40	690.09	1.42	
	Covariate (X)	0	0.00	0.00	0.00
	Error	563	484.74		
Small parr on fry					
	Stream order	4	1,144.34	16.00	
	Years	9	214.61	3.00	
	Interaction	36	69.24	0.97	
	Covariate (X)	1	4,470.72	62.51	0.14
	Error	476	71.52		
Large parr on small parr					
	Stream order	4	76.76	8.78	
	Years	9	29.84	3.41	
	Interaction	36	10.38	1.19	
	Covariate (X)	1	1,220.80	139.70	0.18
	Error	478	8.74		

TABLE 5. A. Mean annual fry and adjusted mean annual small- and large-parr densities, by stream order, for the Miramichi River, 1970-80. B. Significantly different stream orders based on densities within the fry, small- and large-parr categories for the Miramichi River, 1970-80.

A

Juvenile stage	Stream order 2	3	4	5	6
	Mean annual densities (no./83.6 m^2)				
Fry	23.99	16.50	26.70	13.81	21.60
Small parr	13.99	8.11	10.98	4.62	3.26
Large parr	5.48	2.57	3.12	1.84	1.94

B

	Differences between stream order			
Fry:	$2 > 3^2$	5^1		
	$4 > 3^1$	5^1	6^2	
	$6 > 5^1$			
Small parr:	$2 > 3^1$	4^2	5^1	6^1
	$4 > 3^1$	5^1	6^1	
	$3 > 5^1$	6^1		
Large parr:	$2 > 3^1$	4^1	5^1	6^1
	$4 > 5^1$	6^1		

[1] $p < 0.001$
[2] $p < 0.05$

Table 6. A. Unadjusted mean annual fry, small-parr and large-parr densities by stream order, for the Miramichi River, 1970-80. B. Survival rates for fry to small parr and small parr to large parr for each stream order of the Miramichi River, 1970-80.

A

Juvenile stage	Stream order 2	3	4	5	6
	Unadjusted mean annual densities (no./83.6 m^2)				
Fry	23.99	16.50	26.70	13.81	21.60
Small parr	14.18	7.57	11.91	3.79	3.38
Large parr	6.18	2.57	3.95	1.21	1.10

B

Juvenile stage	Stream order 2	3	4	5	6
	Survival rate				
Fry to small parr	0.59	0.46	0.45	0.27	0.16
Small parr to large parr	0.44	0.34	0.33	0.32	0.32

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POOR

QUALITY

ORIGINAL